CONSIDERATIONS ON EQUIPMENT, METHODS AND STANDARDS OF ACCURACY APPLICABLE TO AERIAL SURVEYS FOR DIFFERENT PURPOSES

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by

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TO: K. B. Woods, Director
Joint Highway Research Project — April 4, 1957

FROM: H. L. Michael, Assistant Director — File: 1-1

Attached is a technical paper entitled, "Considerations on Equipment, Methods and Standards of Accuracy Applicable to Aerial Surveys for Different Purposes," by Robert D. Miles, research engineer on our staff. This paper was presented as part of a symposium topic presented at the Highway Research Meeting in January. It briefly presents the various methods of using aerial surveys and photogrammetric maps in highway engineering investigations.

The paper will be submitted to the Highway Research Board for publication by that organization.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Secretary

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TECHNICAL PAPER

CONSIDERATIONS ON EQUIPMENT, METHODS AND STANDARDS OF ACCURACY APPLICABLE TO AERIAL SURVEYS FOR DIFFERENT PURPOSES

by

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Synopsis

This paper is a discussion of the various methods of using aerial surveys and photogrammetric maps in highway engineering investigations. Scales of photographs, mosaics, and maps for different purposes are discussed along with horizontal and vertical accuracy requirements.

The paper briefly reports on an investigative study that is being made for the State Highway Department of Indiana to develop directly from large scale aerial photographs bridge site topographic maps at a scale of 30 feet per inch. Equipment considerations are presented for a proposed photogrammetric system in Indiana which will include an aerial camera, processing laboratory, and photogrammetric plotters.

INTRODUCTION

The purpose of this paper is to give thought to, with a view to purchasing, accepting or adopting aerial surveys for different purposes. In these considerations it is necessary to discuss equipment, methods, and standards of accuracy applicable as well as the purposes for which the aerial surveys are to be used.

Aerial surveys are used for many purposes, but for the highway engineering profession they may be grouped under three major headings: route reconnaissance, preliminary route location, and design location studies. Under each of these headings the product of the aerial survey, the aerial photo with perspective projection and/or the photogrammetric map with orthographic projection, has many uses. To the highway engineer these uses are: land use studies, soil studies, drainage studies, right-of-way studies, and geometric design studies which would include earth-work computations. It is beyond the scope of this paper to go into the techniques of how to make these various studies as innumerable articles are available in technical journals of the American Society of Photogrammetry, American Congress on Surveying and Mapping, American Society of Civil Engineers and in publications of the Highway Research Board. Highway engineers should research these articles and determine the techniques that are applicable within their field of interest.

AERIAL SURVEYS

In this paper, aerial surveys are considered to be of three types: (1) Individual photography, including vertical and oblique; (2) Photo Mosaics, including uncontrolled or controlled; and (3) Photogrammetric Maps including 1-, 2-, and 5-foot contour maps and also large scale cross sectional diagrams for design plans.

There are three methods available for obtaining the aerial surveys mentioned above. One method is by contracting with photogrammetric companies for the particular type of survey desired. This method requires the compilation of a set of specifications for the end product desired - individual photos, photo mosaics, photogrammetric maps or any combination of the three. To assist the highway engineer in specification writing, the Photogrammetry for Highways Committee sponsored by the American Society of Photogrammetry and the American Congress on Surveying and Mapping have prepared a Reference Guide Outline which may be obtained at nominal cost from the Superintendent of Documents (1). This method has the advantage that it, in effect, increases the productivity of a highway department without increase in personnel.

A second method for obtaining aerial surveys is to contract for items one and two mentioned above, and within the framework of a Preliminary Engineering Section of the Highway Department to prepare the photogrammetric maps desired. Production is controlled by the ability of the Highway Department to plan projects so that advantage can be taken of seasonal conditions to secure all the necessary photography for six to eight months of operation.

The third method is to have an Aerial Engineering Section fully equipped with an airplane, camera, photo processing facilities and photogrammetric plotters to perform the complete operation. This method has the advantage that the highway department has complete control over the procedures. Production is limited by the number and type of plotters and the availability of trained personnel.

Route Reconnaissance

Most of the State Highway Departments use aerial photographs in various stages of route reconnaissance studies. A practical combination is to use readily available Department of Agriculture photographs at an approximate scale of 1:20,000 in conjunction with the 7½-minute National Topographic Quadrange Series of maps enlarged to the scale of the photos. The only equipment necessary for route reconnaissance using available airphotos is a simple lens stereoscope or, if preferred, a mirror stereoscope with binocular attachment. Uncontrolled mosaics of a large area can be readily assembled by using alternate photos in a flight line for use in route reconnaissance, and the individual photos in this mosaic oriented with respect to auxillary stereo photos are easily observed by use of the lens or mirror stereoscope.

If the governmental photographs are over six to ten years of age it would be advisable to obtain reconnaissance photography of the area of interest. This new photography should be obtained at a scale range between 1,500 to 2,500 feet per inch. Since land use, drainage, urban areas and general topography are the major controls and since the photos would not be used for topographic mapping in reconnaissance the photographs could be obtained with a 12-inch focal length camera.

To assist in route reconnaissance, especially in areas that are deficient in topographic map coverage of the $7\frac{1}{2}$-minute series, it would be practical to purchase sets of stereoscopic airphoto coverage for the development of mosaics or photo maps using $7\frac{1}{2}$-minute quadrangles as the map size. These mosaics could be prepared at an approximate scale of 1:20,000 by using available governmental photos and existing ground control. Mosaics would be assembled using the effective coverage of each individual photo cut and fitted to the adjacent photo. The mosaic would then be copied photographically and printed to a scale of 1:24,000. It probably would not be possible to obtain ratioed photographs from the governmental agencies for development of controlled mosaics, but even without the ratioed prints a good reconnaissance photo map could be developed if local relief is not too great.

These photo maps would be invaluable in all phases of engineering planning. Watershed areas and land use could be determined with ease. Urban and rural land use would be shown in detail, and the maps would provide a means of selecting feasible highway routes in a minimum of time.

It is believed that these photo maps could be prepared very economically since fairly recent photo coverage is readily available in most areas. Semiskilled labor could be used by the highway department to develop such maps or photogrammetric concerns might be interested in developing these maps on a state wide basis. The cost of the map preparation could be recovered by sales to other interested parties.

The photo maps described above would not be precise maps especially in areas of high local relief. The photo maps should be annotated to show plane coordinate grid lines, and it would be expected that the grid would be plotted to an accuracy of one-fiftieth of an inch or better at the map scale. Photo images should be accurate to at least one-fifth inch of true coordinate position. Accuracies of this type should enable the highway engineer to select the controlling points of various alternate routes of a highway in moderate relief to within practical working limits for reconnaissance surveys.

Preliminary Route Location

Medium scale aerial photographs, photo mosaics and topographic strip maps are required for preliminary route location studies. The general practice in rural areas is to obtain photographs at a scale of about 1000 feet per inch with a six-inch focal length camera or 800 feet per inch with a 8 1/4-inch focal length camera. In commercial practice the 6-inch focal length is generally used. These scales can be enlarged by the photogrammetric plotter to a map scale of 200 feet per inch annotated with five-foot contours. In highly developed areas, the accepted practice is to obtain photographs at a scale of 500 feet per inch or 400 feet per inch with 6-inch or 8 1/4-inch cameras respectively. The topographic map then may contain a strip of terrain up to one-half mile wide at a scale of 100 feet per inch annotated with two-foot contours.

It should be understood that the various photogrammetric plotters used in this country have enlarging factors varying from three to twelve diameters. The enlarging factors combined with the contour interval desired determine, to a large extent, the original scale of the airphotos. It is believed that negative scales smaller than 1000 feet per inch do not provide the detail that is needed by the engineer in preliminary route studies, especially in urban areas, even though these smaller scales may be used on some photogrammetric plotters to prepare an accurate topographic map with a five-foot contour interval. If only the topographic map is to be used in location studies, then the scale of the photograph is controlled by the photogrammetric compilation system. In highway engineering it is believed that both the maps and photographs are needed in preliminary location studies; therefore, the original scale of the photographic negative is an important item. Often it may be desirable to obtain photo scales at 600 or 800 feet per inch and still compile the maps at a 200 foot per inch scale by reduction techniques.

In preliminary location studies, it is advisable to secure low oblique photographs in conjunction with vertical photography. Low oblique photographs should be secured at a ratio of five to one or ten to one with respect to each vertical along the line of flight. The low obliques taken from the nose of the aircraft should be secured with a 12-inch focal length camera. They will present a perspective view that will assist greatly in the preliminary location analysis and in presentation of data especially in highly developed areas or at proposed interchanges.

Vertical aerial photographs for preliminary location studies and for the compilation of strip topographic maps at a scale of 200 feet per inch or 100 feet per inch should be secured with a precision cartographic camera of the proper focal length.

The distortion characteristics of the camera lens should be known, and, if necessary, compensating distortions should be designed into the photogrammetric plotter to reduce all distortions to an absolute minimum. These items would not be important to the highway department that contracts for all photogrammetric work, but to the highway department that buys photography these items can make or defeat the over-all photogrammetric system. The specifications for photography in this case should include maximum and minimum values of distortion or a description of the distortion correction system, and require a Bureau of Standards or other testing agency report to compare the systems. If the camera used for photography has different distortion characteristics than can be compensated by the photogrammetric plotter, than a delay will ensue while corrections are made to the plotter.

The accuracies of aerial photos, photo mosaics and photogrammetric contour maps used in preliminary location studies are comparable to those taken by other methods and are within practical working limits. The general accuracy requirement for contours is that ninety percent of the elevations determined from the solid line contours shall not vary from true elevation by more than one-half contour interval. The remaining ten per cent should not vary more than a full contour. In heavily wooded areas the contours should be dashed, and the accuracy such that ninety percent of the elevations determined from the dashed-line contours would be correct to one contour interval or one-fourth the average height of the ground cover, whichever is the greater (1). In dense wooded areas it would generally be necessary to survey by field methods especially in coniferous regions

The state plane coordinate grid should be an essential part of the map and should be accurately plotted to within one-hundredth inch of true grid value. Selected horizontal control points measured in the field also should be accurately plotted to within one one-hundredth inch of true position. Planimetric details should be within one-fiftieth of an inch of true position when measured to the nearest grid, and spot elevations on the map should be accurate to one-fourth the contour interval.

Ground control is an essential part of any photogrammetric survey Horizontal and vertical control monuments should be placed at intervals along the proposed line so that they may be recovered by field crews. The interval for horizontal control should be about 1000 feet for preliminary surveys, and points should be referenced to the state plane coordinate system. These points should be advantageously located so that the preliminary center line can be located on the ground to within a few feet of true position. The lateral tolerance used on the Ohio Turnpike was 10 feet (4). With good ground control a mathematical solution of the location can be developed for preliminary staking in the field, with final adjustment made by the field location engineer.

Design Location

The application of photogrammetry and aerial surveys to design location studies is the ultimate development for which highway engineers are searching. This requires the accurate measurement of all possible details for preparing construction plans, estimating earthwork quantities, final measurement of earthwork quantities, if necessary, and securing of right-of-way. In some cases certain phases of this ultimate plan have been reached as reported in California, Ohio and Pennsylvania (4, 5, 8, and 12).

One method of developing the approximate solution of the design location problem is to survey in the field the center line as determined by the preliminary survey discussed previously. Centerline profiles are obtained after necessary adjustments are made to fix the positions of tangent intersections. If ground detail is insufficient control points along this line are then signalized by the use of cloth, lime, paint or other contrasting material that will photograph from the air. A flight line to produce individual photo scales of 250 or 200 feet per inch for 6-inch or 8¼-inch photography respectively is made. Glass diapositives made from this photography are used to plot planimetric maps along the preliminary center line at a scale of 50 feet per inch. These same diapositives are then used to develop spot elevation information for use in plotting cross sections. Under ideal conditions when vegetation is low or nonexistant, it is reported that photogrammetric spot elevations are accurate to plus or minus 0.2 of a foot (3). Under average conditions the vertical accuracy is plus or minus 0.5 of a foot even though the photogrammetric readings are interpolated and recorded to 0.1 foot of elevation using a foot reading plotting table. Horizontal accuracies are of the order of one to two feet measured at a map publication scale of one-inch equals fifty feet.

The final location is then resolved by making a paper location using the planimetric map, contact airphotos, and cross sectional information to fit the natural and cultural terrain conditions and other geometric considerations. The large scale of these items enables the engineer to select the controls for the final location of the highway. Frequently the paper location is then reduced using a process camera to a scale of one-inch-equals-one-hundred-feet and traced to produce road plans.

In some cases the preliminary location is not surveyed in the field, but is used only as a flight plan to secure large scale photographs for preparation of topographic maps at a scale of 50 feet per inch with one- or two-foot contours. In this case the engineer uses the maps to further refine the final location before actual field surveys. This method does not necessarily require the measurement of spot elevations for cross sections. Various final location lines are studied by interpolating between contours or by drawing the proposed contours of cuts and fills and measuring volumes of the wedges produced. About the same accuracies are achieved by this method as before, and both methods should produce earthwork estimates within two to five percent of the estimates determined by normal field procedures.

Another application of aerial surveys and photogrammetry to highway design studies is in the field of site plan preparation. Stream crossings, grade separations, interchanges and other items requiring site plans at scales of 20 to 50 feet per inch fall in this category. These site plans are prepared with contour intervals of one or two feet. The minimum ground control necessary for surveys of this type is four vertical control points and two horizontal control lines for scale for each stereoscopic pair of aerial photographs. A rapid method of determining the horizontal control is by the use of a two meter subtense bar and a second-reading theodolite.

Some agencies prepare these site plans at scales of 40 to 50 feet per inch in photogrammetric plotters and then enlarge these photographically to scales of 20 feet per inch. In this manner any drafting inaccuracies are increased by the amount of the enlargement.

The Indiana State Highway Department generally prepares site plans at a scale of 50 feet per inch. The Joint Highway Research Project at Purdue University is investigating the possibility of preparing these maps from aerial photographs secured at a scale of approximately 150 feet per inch with a 6-inch Metrogon precision mapping camera. For this project the photography and diapositive plates were secured by contract.

The glass diapositives 0.06 inches thick are printed emulsion side up, and are projected in a Kelsh Plotter at a five diameter enlargement to a scale of 30 feet per inch. Most of the models developed in the Kelsh Plotter at these scales appear to be of excellent quality, and the image motion that was expected has not necessarily occurred. Photography of this type requires a very slow flying speed (80-100 m.p.h.), fast shutter speed, and rapid rewind cycle. Image motion greater than one one-hundredth of an inch can normally be detected, and in all probability would prohibit accurate measurements. Some difficulty has been encountered due to the inability of the vacuum system to take hold in the extremely short time between exposures. The negative is therefore not flat during the exposure cycle. This can be corrected by shortening the rewind cycle of the camera. This project is in its infancy, but at a later date it is expected that an analysis will be made of several site plans to determine vertical and horizontal accuracies.

EQUIPMENT

In the consideration of equipment, it is believed advantageous to present the experience of the State Highway Department of Indiana as an example. The author has worked extensively with the Department in determining needs and type of equipment for the proposed development of the complete photogrammetric system. The Department has available an airplane of the twin engine type that is suitable for conversion into a photographic plane. Equipment considerations therefore revolved around the aerial cartographic camera, the photographic processing laboratory, and the photogrammetric plotters.

Aerial Camera

The first consideration is the focal length of the camera lens desired. The lens should be of a type that has high resolving power under the operating conditions planned and either be distortion-free or have a narrow range of distortion that can be compensated or removed in the photogrammetric mapping system. Focal lengths may vary from four inches to twelve inches or more. In general, large angular field as obtained in the shorter focal length systems is desired because of less flying, fewer photographs, less ground control, and a higher mapping accuracy due to the larger angle between intersecting rays which indicate parallax. The 6-inch camera, as mentioned previously, is the one generally used by the photogrammetric mapping companies. The 8 1/4-inch lens or longer focal lengths are better suited for mosaic photography or land-use study.

The next consideration is the cycling time. Most of the work of the Department is going to be very large scale photography which requires cycling times of 2 to 3 seconds at aircraft speeds of 80 to 150 mph. Most cameras recycle in 3 or 6 seconds.

The cameras considered were the government surplus cameras designated K3B, K17B, K17C, and T5, and the new Fairchild T11(11). The first three are charting cameras that must be converted to precision mapping cameras. The last two are precision topographic cameras. The information available on these cameras indicated that only the K17C 6-inch camera was equipped to recylce in less than two seconds (11). This camera has a recycle time of 1 1/4 seconds which would enable higher aircraft speeds for more stable flight.

It was decided that the K17C converted to a 6-inch Metrogon precision mapping camera and tested for distortion characteristics by the Bureau of Standards would fulfill the expected needs of the highway department. Auxiliary equipment for the camera included the camera mount, extra magazines, intervalometer, dynamotor for converting to 24-volt electrical system, electrical cables, and equipment for producing a vacuum for film flatness control.

Processing Laboratory

The processing laboratory is considered as a three phase system with separate darkroom facilities for film processing, print processing, and enlarging. The important pieces of equipment to consider are film developers, film dryers, water jacketed film processing units, large stainless steel sinks and water temperature control devices for the film processing room. The print processing room requires such items as large stainless steel sinks and trays, electronic printers to control density of diapositive plates, 10-inch by 10-inch contact printers, 4 by 5 enlarger, 40- to 60- inch diameter print washers, and large matte and gloss print dryers. The enlarging room requires large stainless steel tanks and trays, rectifying enlarger for aerial roll film 9½ inches wide, and a 24- or 36-inch process camera for copying mosaics and enlarging or reducing photogrammetric maps. Miscellaneous supplies for the laboratory would include diapositive plate hangers, various sizes of graduates, and 10- to 50-gallon storage tanks and mixing crocks. It was estimated that the equipment would require about 1000 square feet of floor area, and cost about $18,000 with some items being rebuilt units or surplus.

The actual selection of the various manufactured models of the individual items mentioned above is naturally an economic study. Compromises are made to fit immediate needs, availability of space and available electric current supply. This last item can be a considerable cost item in an already overloaded electric system.

Photogrammetric Plotters

There are numerous photogrammetric plotters, and each has particular advantages or applications for surveying purposes. Private photogrammetric mapping organizations or the Federal mapping organizations may have a series of plotters with certain types mapping planimetry, others topography and still others bridging control to name just a few of the applications. A few of the photogrammetric plotting machines are listed in Table 1 along with some of the repoted "C-factors" for contours and for spot elevations.

TABLE I
Partial Listing of Photogrammetric Plotters*

Name	Contour C Factor	Spot C Factor
Multiplex	600-800	3000
Balplex, ER55		
Kelsh 6" or 8 1/4"	850-1000	4250
Wild Autograph A5	1000-1200	5000
Wild Autograph A6	900-1100	4500
Wild Autograph A7	1000-1200	
Wild Autograph A8	1000-1200	
Santoni Stereosimplex Model III	1500-2000 (7)*	
Stereoplanigraph C7	1200-1250	6000

* Source of information: Manual of Photogrammetry (11) and various volumes of Photogrammetric Engineering (2) (7) (9)

The "C-Factor" is the ratio of mapping contour interval to the flight altitude. The various plotters are assigned these relative factors based on the experience of the operator, ground control available and field tests of prepared maps. The above factors are actually based on medium and small scale mapping projects with contour intervals of ten and twenty feet. There is some question as to their direct application in large scale mapping as required by highway engineers. It is reported that they can be increased about 30 percent for idea conditions and decreased at least 30 percent under unfavorable conditions of ground with little contrast or highly forested (9).

In the analysis of photogrammetric plotters it is believed that the volume and type of work conducted by a highway department would not justify the expenditure of large sums of money for individual first order universal type plotters. It appears more practical, with limited technicians and small equipment budgets, to have a small group of plotters all performing about the same operations. There are strong arguments against this statement. Of course, the best argument is that ground control for a photogrammetric survey is the expensive item, and to eliminate extensive ground control a first or second order instrument is needed to bridge control and to select individual picture point control for topographic and planimetric mapping.

The ideal conditions are generally realized by the established photogrammetric engineering concerns. Under these conditions the photogrammetric system consists of a first or second order instrument to bridge and develop the base map with coordinate grid and topography and several third order or "single model" instruments are used to plot planimetry and sometimes additional topographic details. This system is ideally suited for area mapping of a city, a reservoir or other regional mapping project, or for preliminary or final location of a highway in excess of say ten miles. It is recommended that for the types of surveys mentioned that advantage be taken of these elaborate systems as suggested by Section 121, Mapping, of Public Law 627 - Title 1: Federal Aid Highway Act of 1956, to increase the productivity of the highway department.

The highway department can increase further its productivity by having a small but adequately equipped photogrammetric section to develop preliminary location plans, final location plans, cross-sections and site plans of short highway sections. Using this premise it is believed appropriate to consider only two photogrammetric plotters of similar capabilities and of comparable price. These two plotters are the Kelsh Metrogon Plotter with either 6-inch or 8 1/4-inch projectors and the Balplex Plotter with ER 55 projectors using 6-inch Planigon or Metrogon photography. Each of these plotters are termed "single model" instruments as they do not lend themselves to extensive bridging applications. The Kelsh Plotter enlarges original negative scale four or five diameters depending upon focal length and the Balplex Plotter 3.4 diameters. The Kelsh Plotter is equipped to handle 9 ½ x 9 ½-inch diapositives contact printed while the Balplex is equipped to handle 4 x 4 -inch diapositives that require a special reduction printer. One reduction printer may serve several Balplex Plotters just as the special electronic printer mentioned previously will serve several Kelsh Plotters. Of course, the special electronic printer is not absolutely necessary as a much more economical contact printer will suffice; although, prints and diapositives will not be of as uniform a quality unless made by a highly skilled darkroom technician.

In the analysis of the needs in Indiana for use in conjuction with the K17C 6-inch Metrogon precision mapping camera it was decided that the 6-inch Kelsh Plotter with a five diameter enlarging factor fulfilled the requirement. Three Kelsh Plotters appear to serve the immediate needs. One plotter will serve the Raod Location Department, another the Bridge Location Department and the third will be used by the Joint Highway Research Project to handle overflow and to investigate additional applications and limitations.

It is expected that the research applications will be developed by graduate civil engineering students, and the instrument will also be used to assist in training plotter operators for the central office. The plotter located at Purdue will also be used on the undergraduate level in transportation and surveying courses to keep the future highway engineers cognizant of modern mapping methods, applications and limitations.

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